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Zhu et al.

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(54) **AUTO-EXPOSURE METHOD USING CONTINUOUS VIDEO FRAMES UNDER CONTROLLED ILLUMINATION**

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(52) **U.S. Cl.**
CPC ***H04N 5/2256*** (2013.01); ***F21V 33/0052*** (2013.01); ***G06K 7/10732*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC .. H04N 5/235; H04N 5/2353; G06K 7/10732
USPC 235/454, 455, 462.01–462.49
See application file for complete search history.

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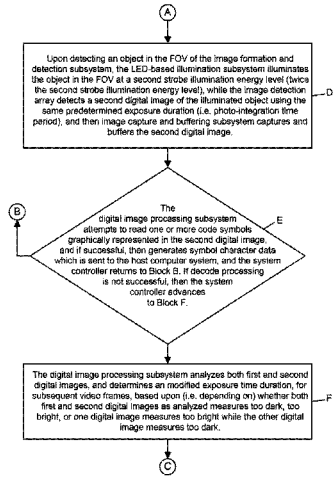
(57) **ABSTRACT**

An illumination control process for use in a digital image capture and processing system includes illuminating an object in the field of view with different pulses of illumination over a pair of image frames, detecting digital images of the illuminated object over these image frames, and decode processing the digital images. In an embodiment, upon failure to read a symbol in one of the first and second images, these digital images are analyzed in real-time, and based on the results of this real-time image analysis, the exposure time is adjusted during subsequent image frames. In another embodiment, upon failure to read a symbol in one of the first and second images, these digital images are analyzed in real-time, and based on the results of this real-time image analysis, the energy level of the illumination is adjusted during subsequent image frames.

20 Claims, 13 Drawing Sheets



(51) **Int. Cl.**

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H04N 5/235	(2006.01)
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F21W 131/30	(2006.01)
F21Y 101/02	(2006.01)

(52) **U.S. Cl.**

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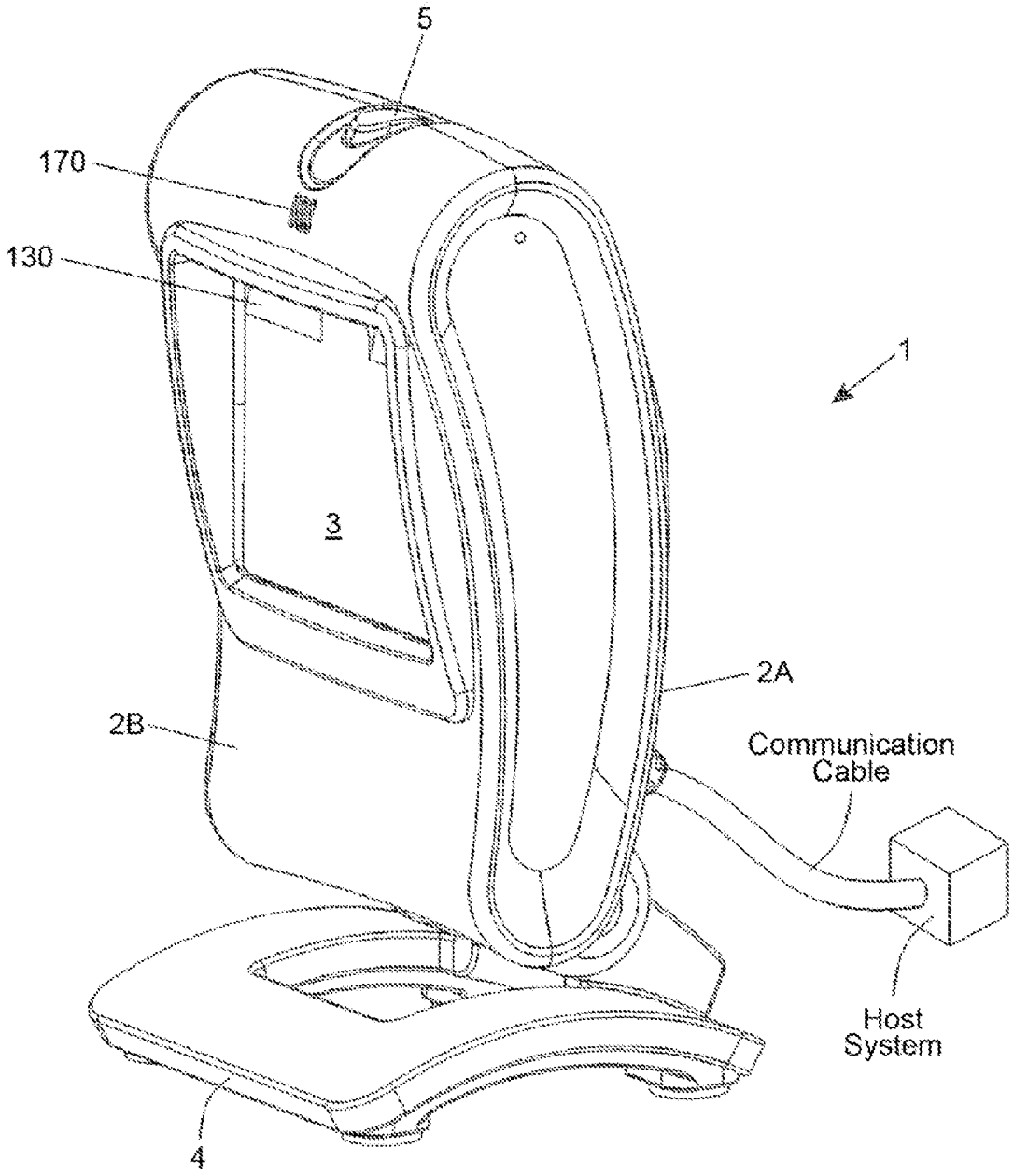

FIG. 1

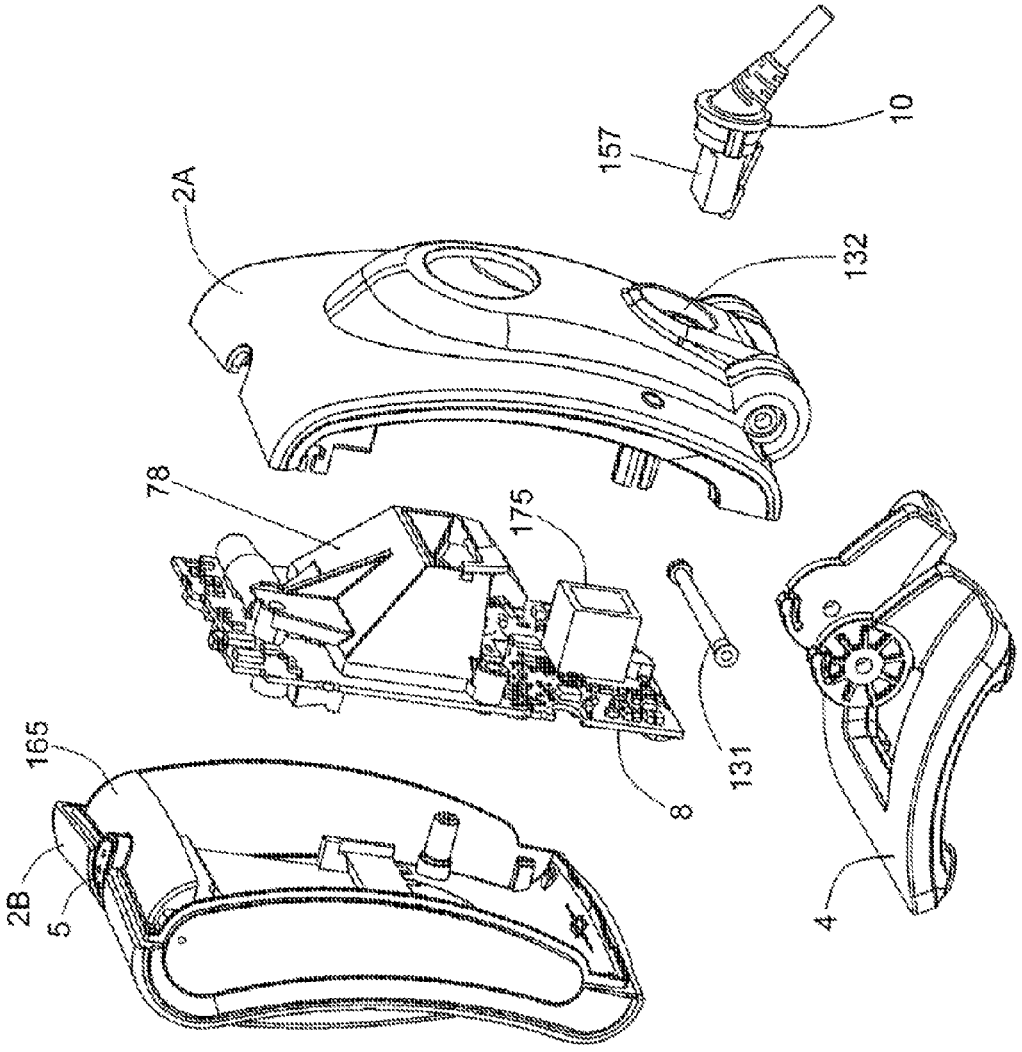

FIG. 2A

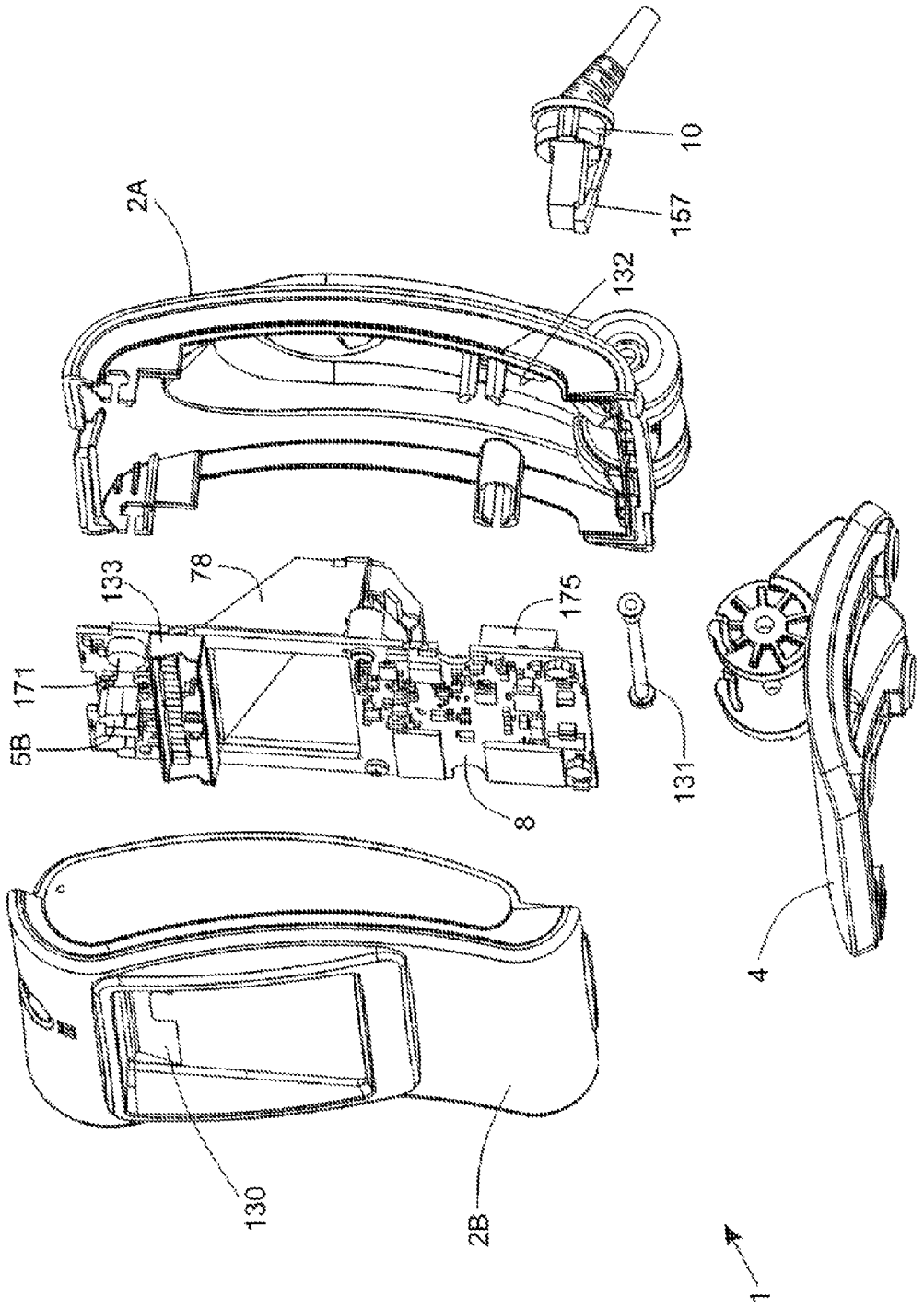

FIG. 2B

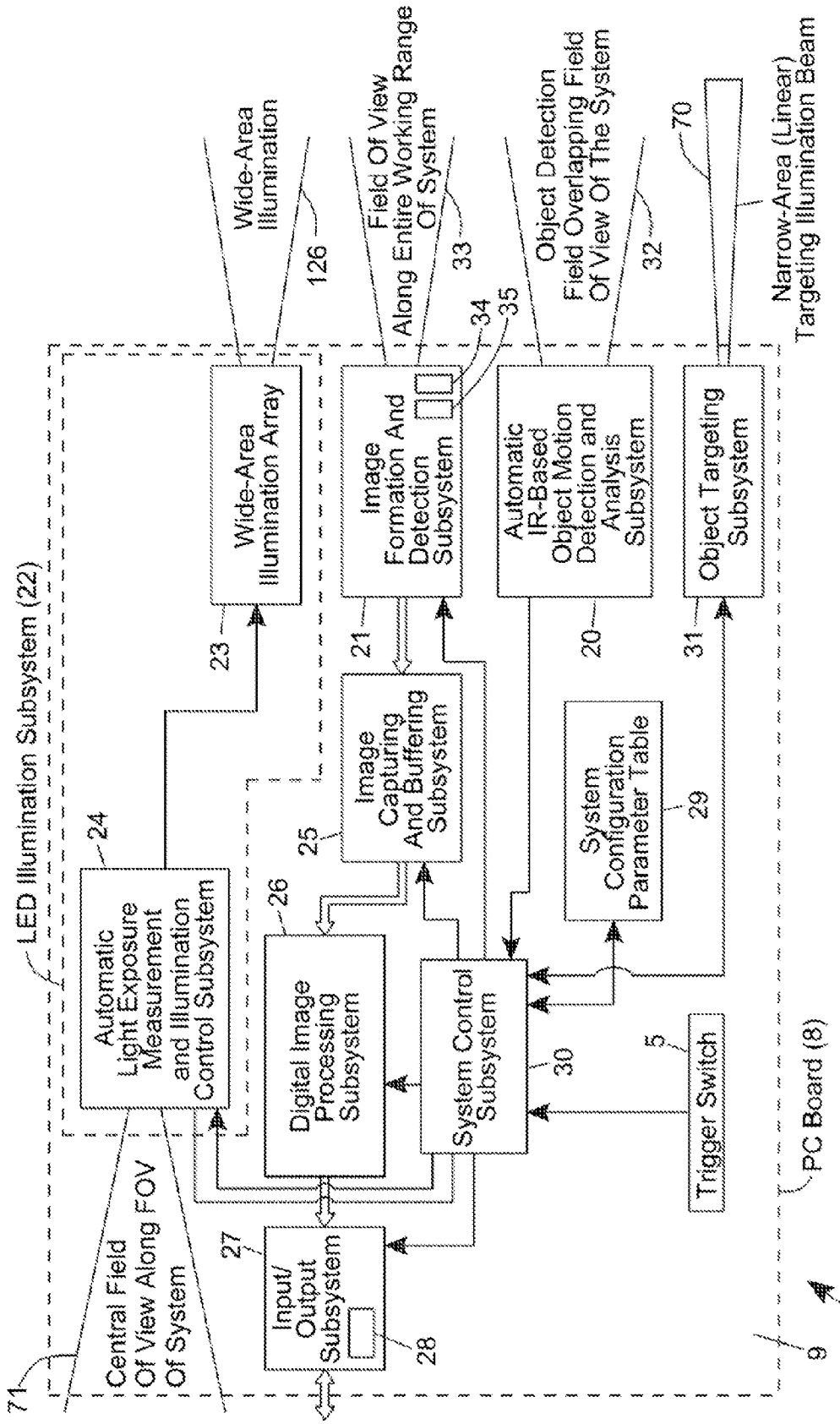
LED Illumination Subsystem (22)
Automatic Light Exposure Measurement and Illumination Control Subsystem
24
Wide-Area Illumination Array
23
Image Formation And Detection Subsystem
21
Automatic IR-Based Object Motion Detection and Analysis Subsystem
20
Object Targeting Subsystem
31
Image Capturing And Buffering Subsystem
25
Digital Image Processing Subsystem
26
System Control Subsystem
30
System Configuration Parameter Table
29
Input/ Output Subsystem
27
28
Trigger Switch
5
PC Board (8)
9
1
71
Central Field Of View Along FOV Of System
Wide-Area Illumination
126
Field Of View Along Entire Working Range Of System
33
34
35
Object Detection Field Overlapping Field Of View Of The System
32
70
Narrow-Area (Linear) Targeting Illumination Beam

FIG. 3

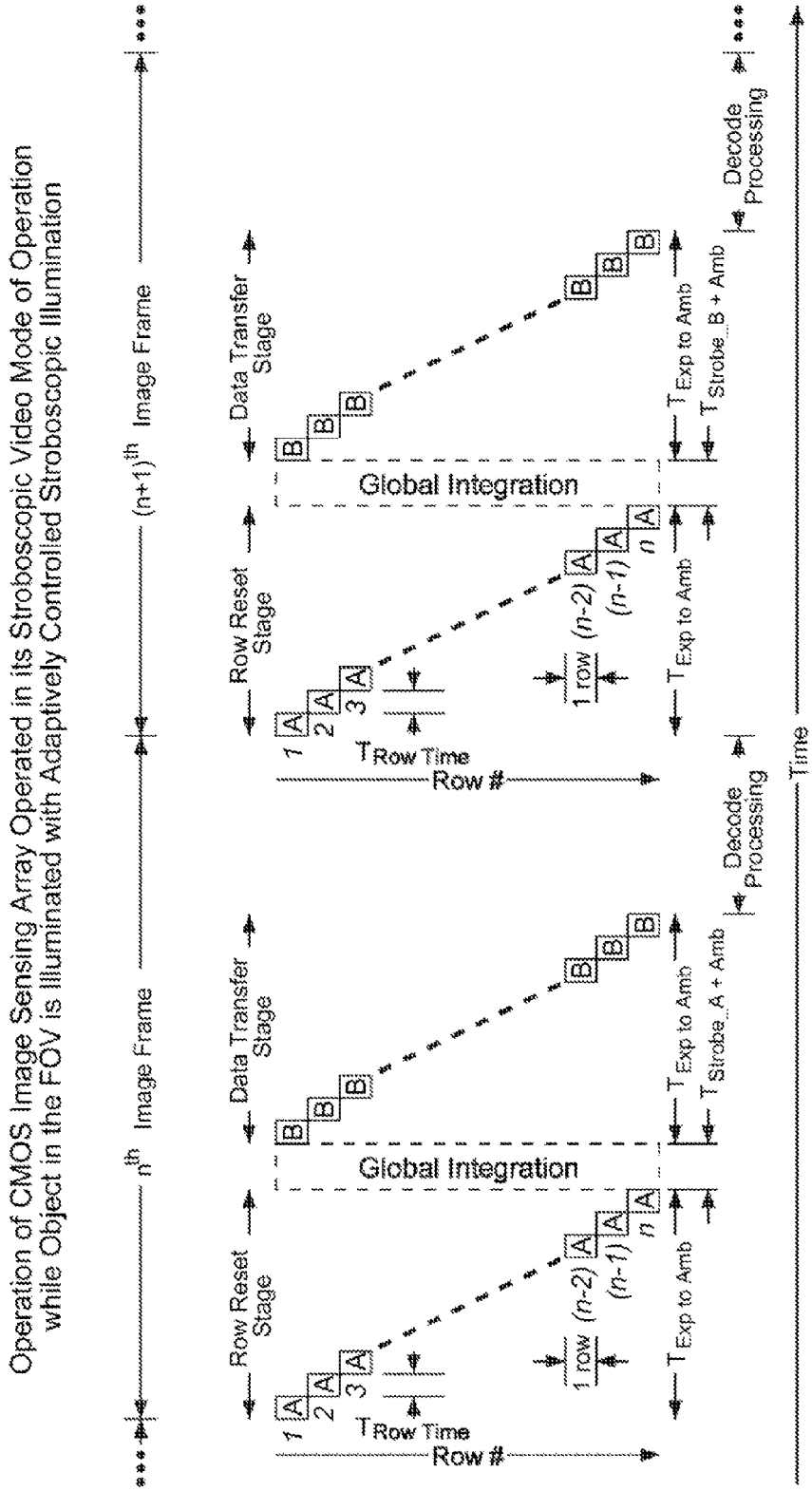
Operation of CMOS Image Sensing Array Operated in its Stroboscopic Video Mode of Operation while Object in the FOV is Illuminated with Adaptively Controlled Stroboscopic Illumination
n th Image Frame
(n+1) th Image Frame
Row Reset Stage
Data Transfer Stage
Global Integration
T Row Time
Row #
1 row
T Exp to Amb
T Strobe_A + Amb
T Strobe_B + Amb
Decode Processing
Time
A = Row Reset Operations
B = Row Data Transfer Operations

FIG. 4

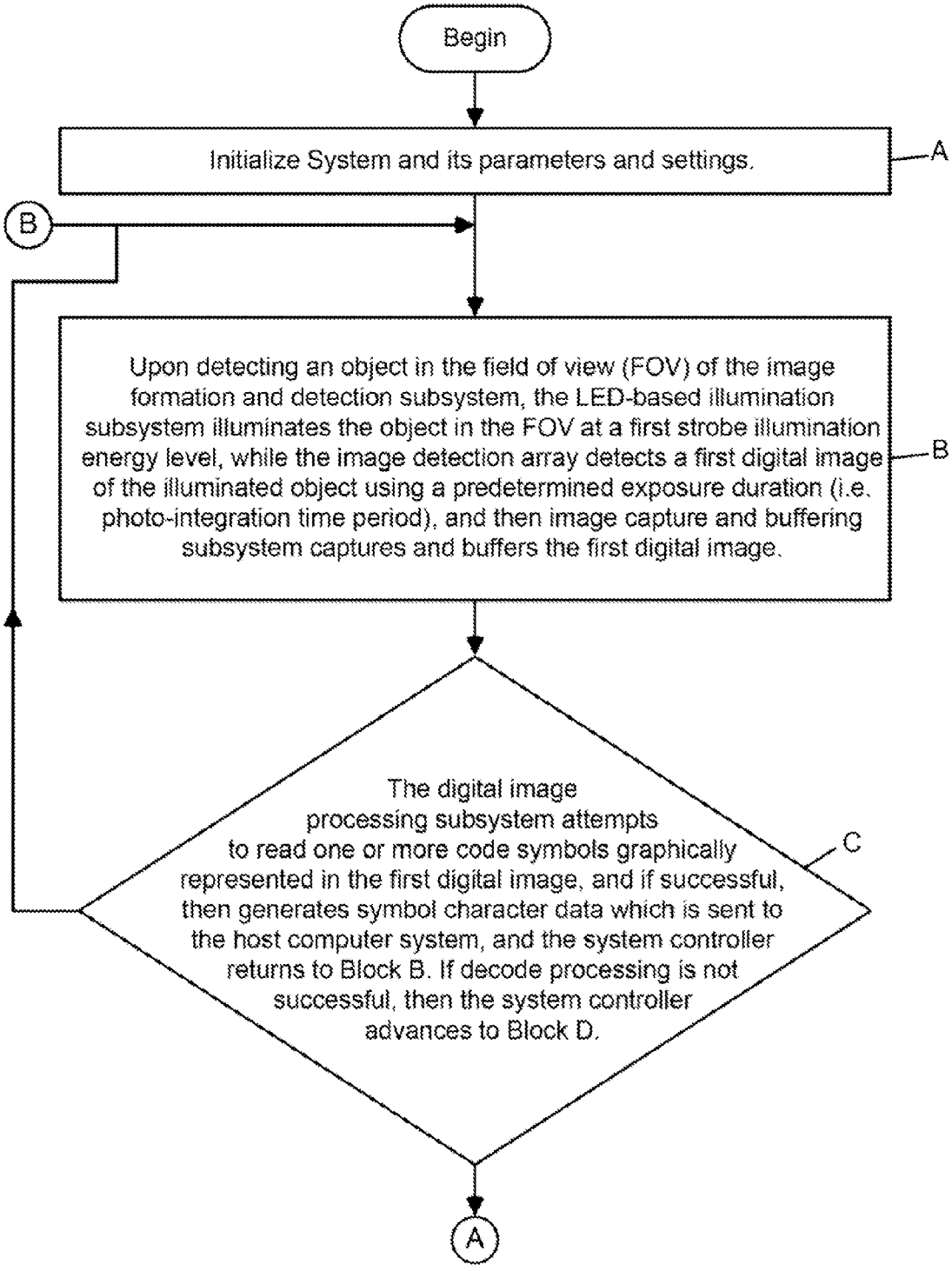
Begin
Initialize System and its parameters and settings.
A
B
Upon detecting an object in the field of view (FOV) of the image formation and detection subsystem, the LED-based illumination subsystem illuminates the object in the FOV at a first strobe illumination energy level, while the image detection array detects a first digital image of the illuminated object using a predetermined exposure duration (i.e. photo-integration time period), and then image capture and buffering subsystem captures and buffers the first digital image.
B
The digital image processing subsystem attempts to read one or more code symbols graphically represented in the first digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system controller advances to Block D.
C
A

FIG. 5A

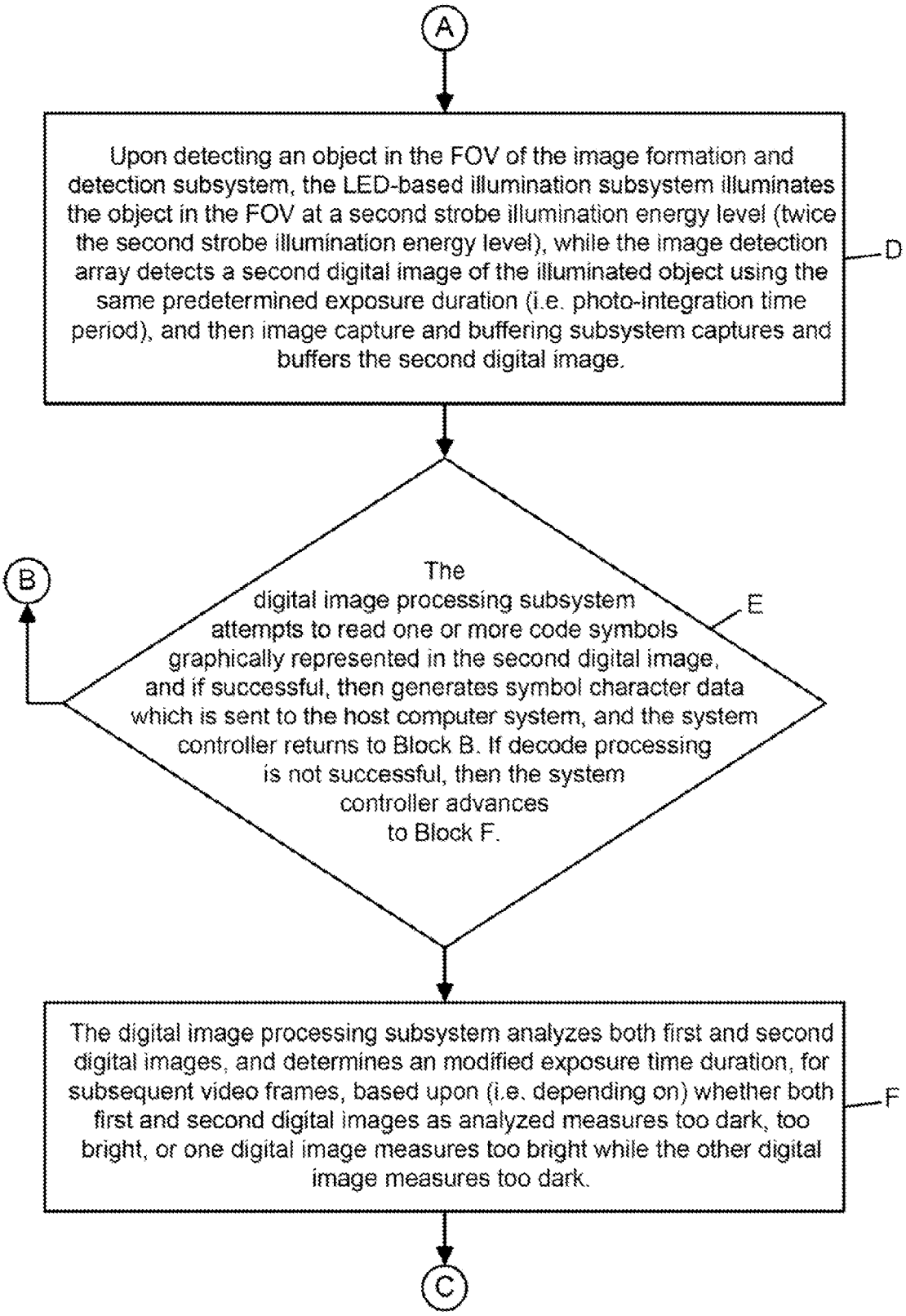
A
Upon detecting an object in the FOV of the image formation and detection subsystem, the LED-based illumination subsystem illuminates the object in the FOV at a second strobe illumination energy level (twice the second strobe illumination energy level), while the image detection array detects a second digital image of the illuminated object using the same predetermined exposure duration (i.e. photo-integration time period), and then image capture and buffering subsystem captures and buffers the second digital image.
D
B
The digital image processing subsystem attempts to read one or more code symbols graphically represented in the second digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system controller advances to Block F.
E
The digital image processing subsystem analyzes both first and second digital images, and determines an modified exposure time duration, for subsequent video frames, based upon (i.e. depending on) whether both first and second digital images as analyzed measures too dark, too bright, or one digital image measures too bright while the other digital image measures too dark.
F
C

FIG. 5B

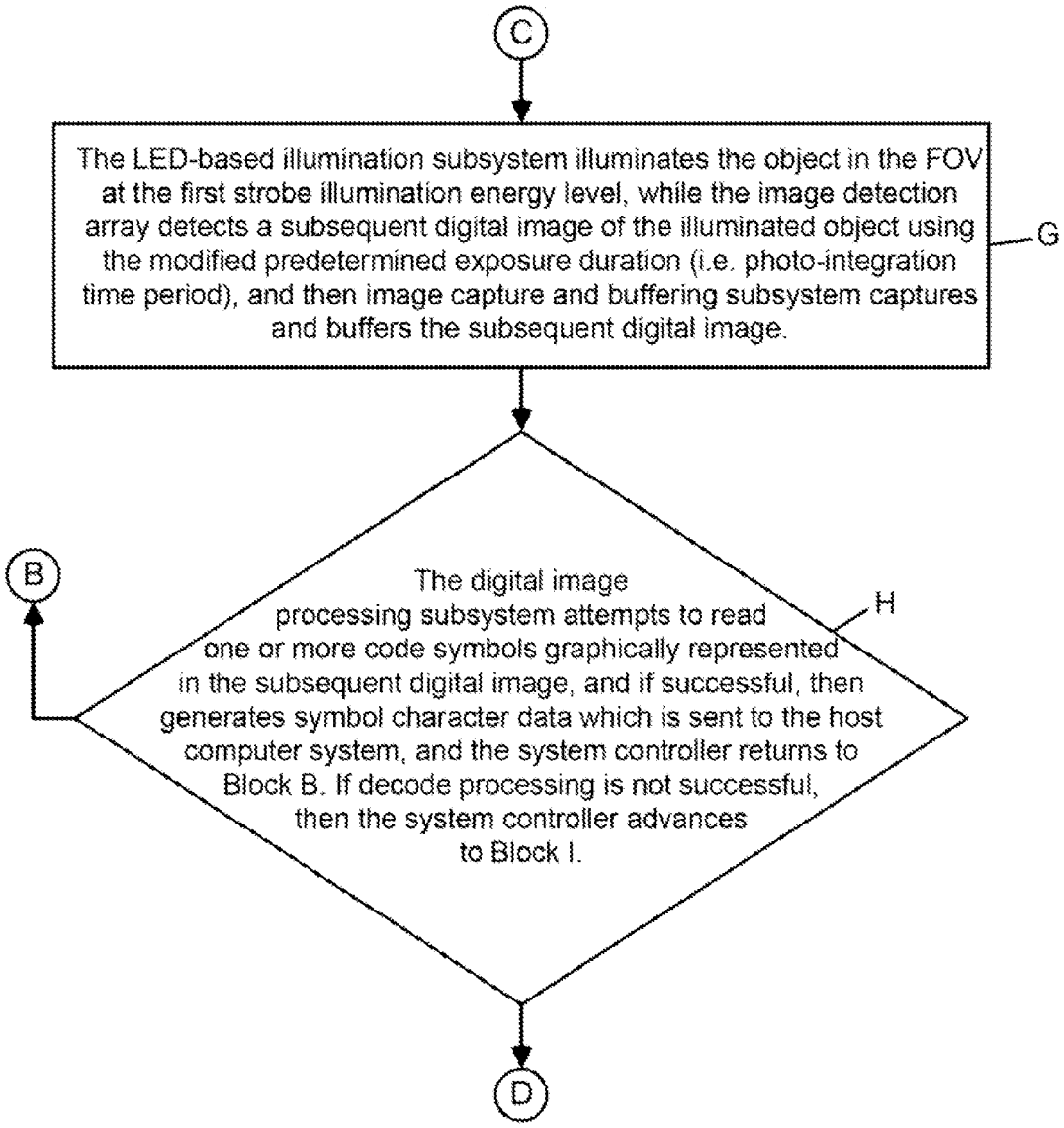
C
The LED-based illumination subsystem illuminates the object in the FOV at the first strobe illumination energy level, while the image detection array detects a subsequent digital image of the illuminated object using the modified predetermined exposure duration (i.e. photo-integration time period), and then image capture and buffering subsystem captures and buffers the subsequent digital image.
G
B
The digital image processing subsystem attempts to read one or more code symbols graphically represented in the subsequent digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system controller advances to Block I.
H
D

FIG. 5C

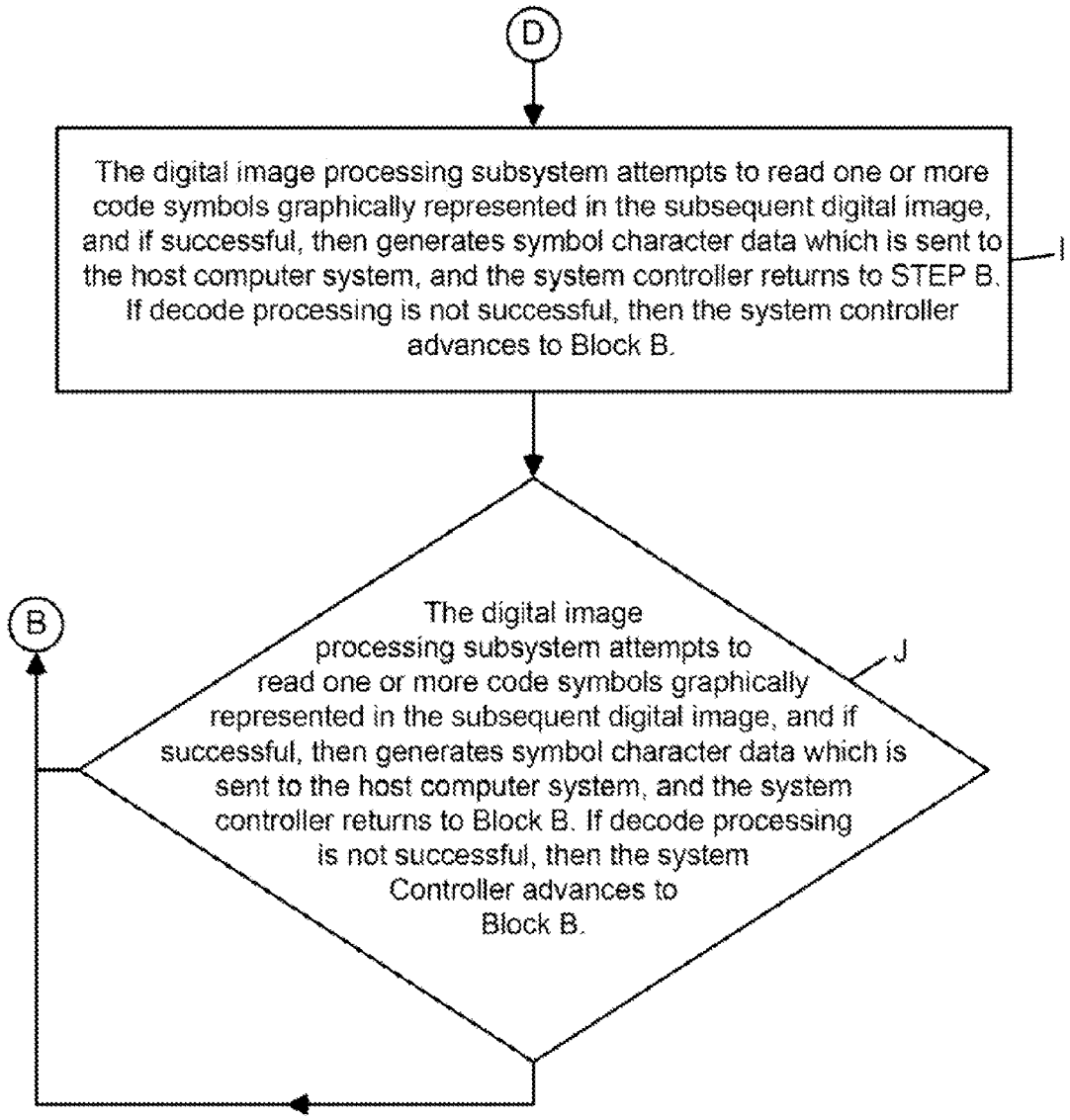
D
The digital image processing subsystem attempts to read one or more code symbols graphically represented in the subsequent digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to STEP B. If decode processing is not successful, then the system controller advances to Block B.
I
B
The digital image processing subsystem attempts to read one or more code symbols graphically represented in the subsequent digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system Controller advances to Block B.
J

FIG. 5D

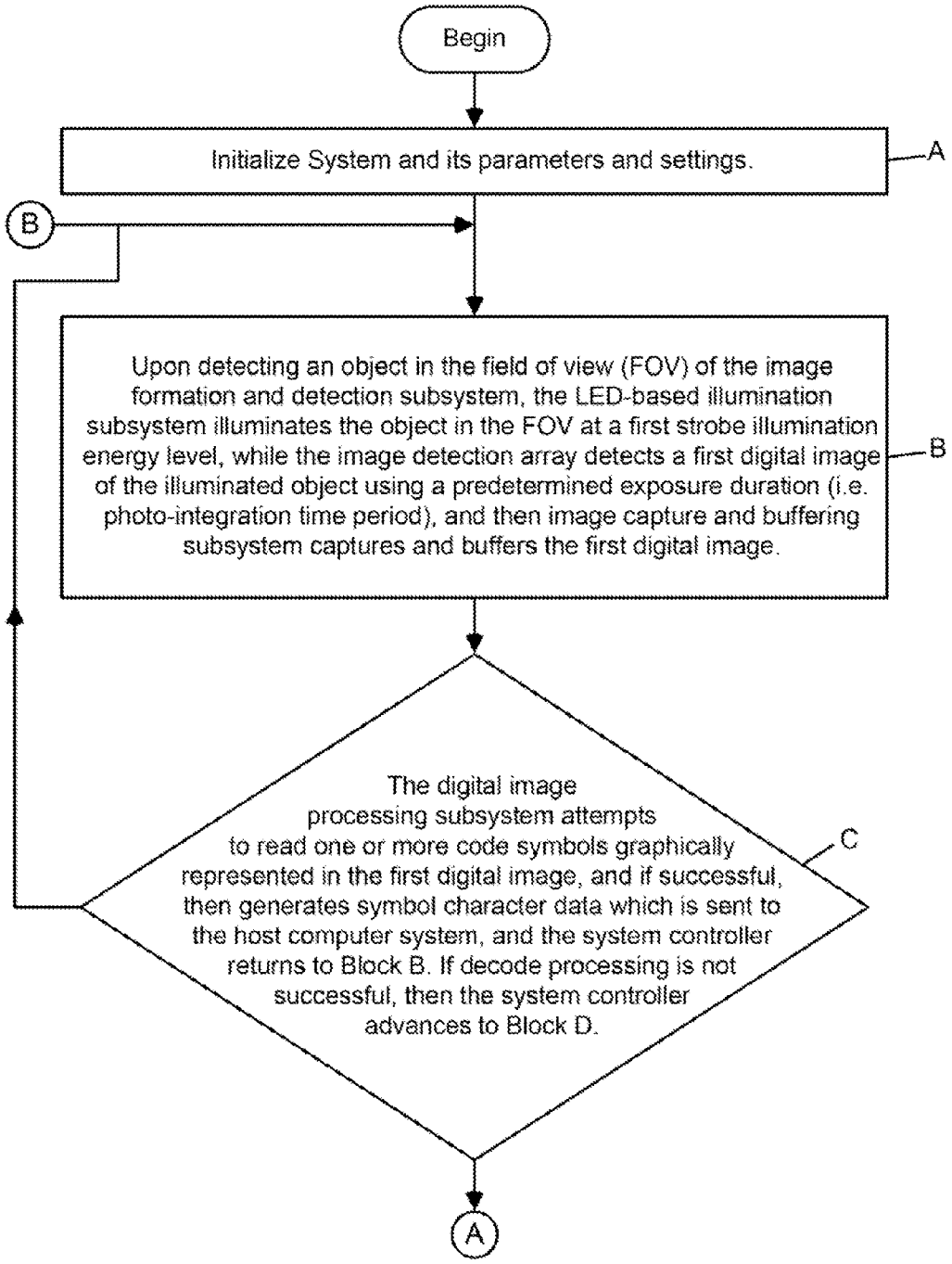
Begin
Initialize System and its parameters and settings.
A
B
Upon detecting an object in the field of view (FOV) of the image formation and detection subsystem, the LED-based illumination subsystem illuminates the object in the FOV at a first strobe illumination energy level, while the image detection array detects a first digital image of the illuminated object using a predetermined exposure duration (i.e. photo-integration time period), and then image capture and buffering subsystem captures and buffers the first digital image.
B
The digital image processing subsystem attempts to read one or more code symbols graphically represented in the first digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system controller advances to Block D.
C
A

FIG. 6A

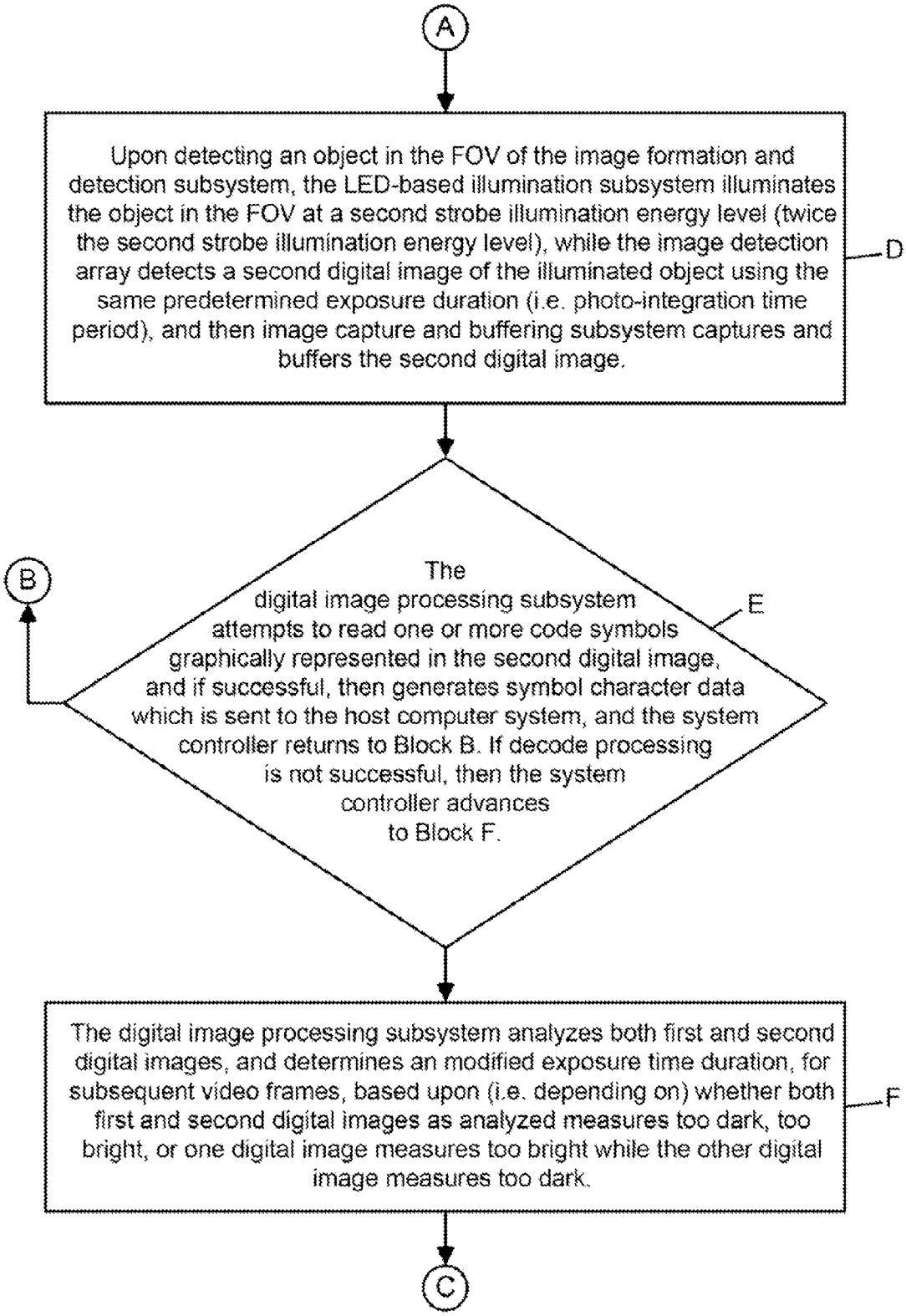
A
Upon detecting an object in the FOV of the image formation and detection subsystem, the LED-based illumination subsystem illuminates the object in the FOV at a second strobe illumination energy level (twice the second strobe illumination energy level), while the image detection array detects a second digital image of the illuminated object using the same predetermined exposure duration (i.e. photo-integration time period), and then image capture and buffering subsystem captures and buffers the second digital image.
D
B
The digital image processing subsystem attempts to read one or more code symbols graphically represented in the second digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system controller advances to Block F.
E
The digital image processing subsystem analyzes both first and second digital images, and determines an modified exposure time duration, for subsequent video frames, based upon (i.e. depending on) whether both first and second digital images as analyzed measures too dark, too bright, or one digital image measures too bright while the other digital image measures too dark.
F
C

FIG. 6B

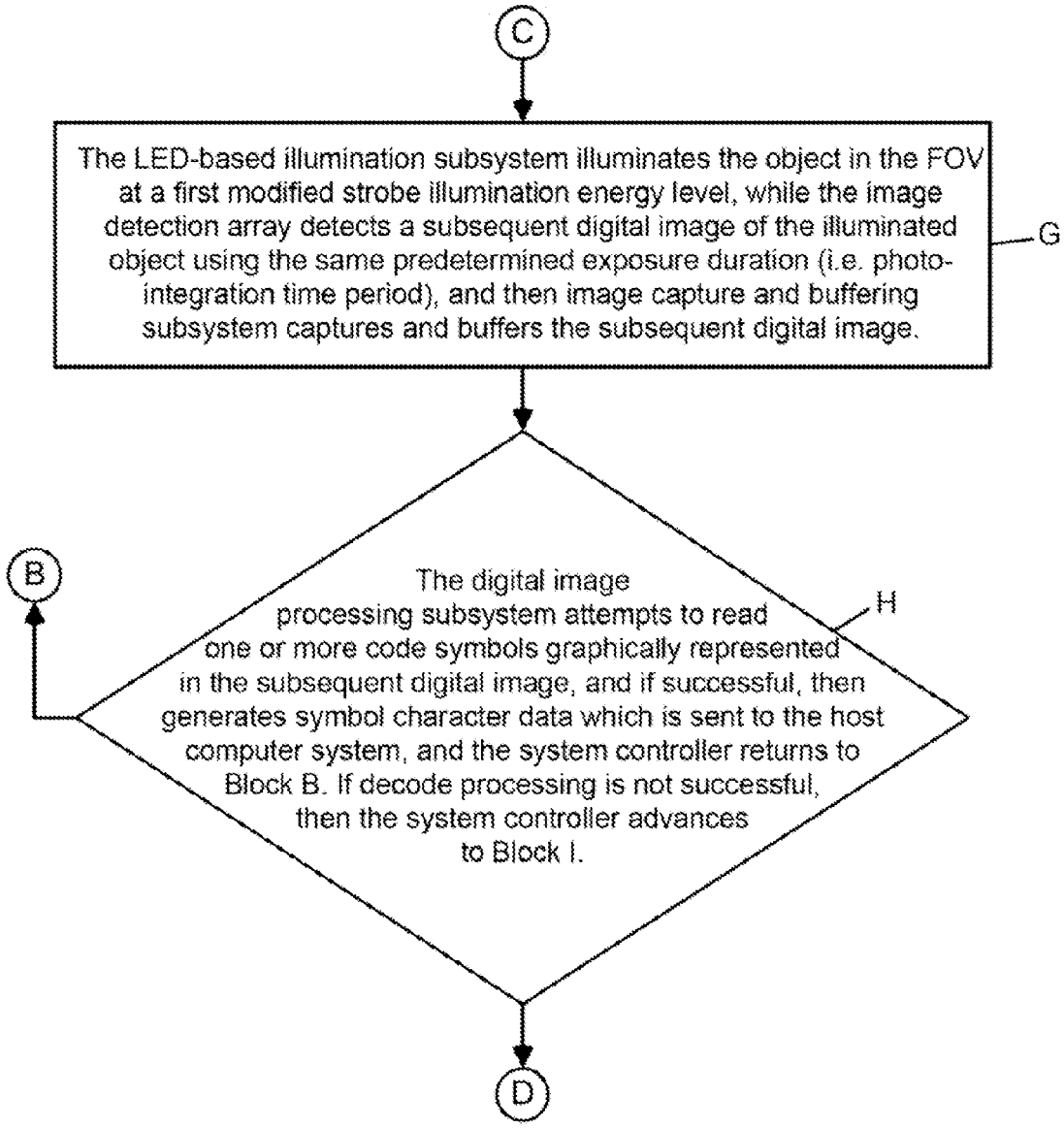
C
The LED-based illumination subsystem illuminates the object in the FOV at a first modified strobe illumination energy level, while the image detection array detects a subsequent digital image of the illuminated object using the same predetermined exposure duration (i.e. photo-integration time period), and then image capture and buffering subsystem captures and buffers the subsequent digital image.
G
The digital image processing subsystem attempts to read one or more code symbols graphically represented in the subsequent digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system controller advances to Block I.
H
B
D

FIG. 6C

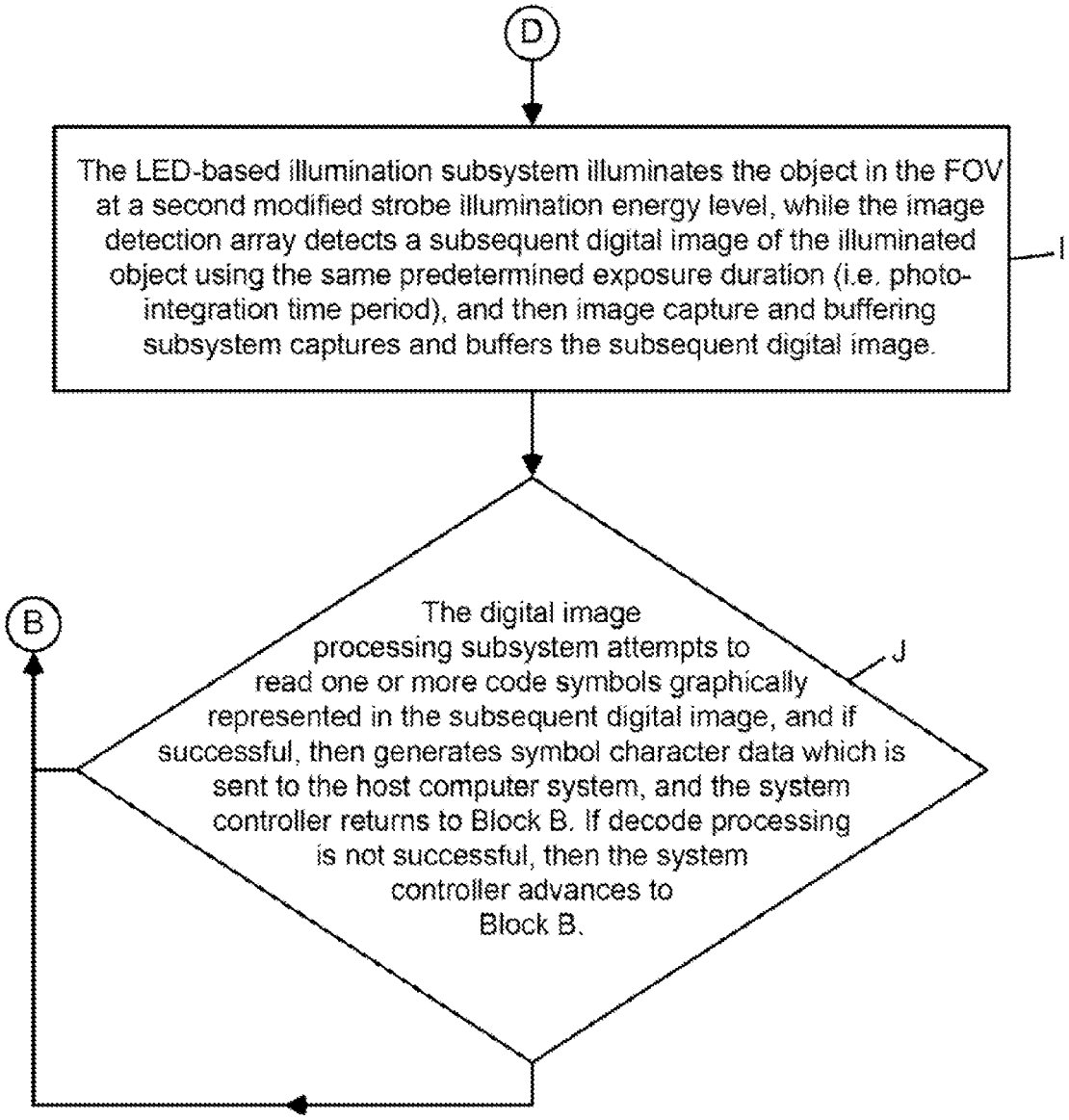
D
The LED-based illumination subsystem illuminates the object in the FOV at a second modified strobe illumination energy level, while the image detection array detects a subsequent digital image of the illuminated object using the same predetermined exposure duration (i.e. photo-integration time period), and then image capture and buffering subsystem captures and buffers the subsequent digital image.
I
The digital image processing subsystem attempts to read one or more code symbols graphically represented in the subsequent digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system controller advances to Block B.
J
B

FIG. 6D

AUTO-EXPOSURE METHOD USING CONTINUOUS VIDEO FRAMES UNDER CONTROLLED ILLUMINATION

CROSS-REFERENCE TO PRIORITY APPLICATIONS

The present application claims the benefit of U.S. patent application Ser. No. 13/852,065 for an *Auto-Exposure Method Using Continuous Video Frames Under Controlled Illumination*, filed Mar. 28, 2013 (and published Aug. 1, 2013 as U.S. Patent Application Publication No. 2013/0194451), now U.S. Pat. No. 8,985,456, which claims the benefit of U.S. patent application Ser. No. 13/020,044 for an *Auto-Exposure Method Using Continuous Video Frames Under Controlled Illumination*, filed Feb. 3, 2011 (and published Aug. 9, 2012 as U.S. Patent Application Publication No. 2012/0199654), now U.S. Pat. No. 8,408,464. Each of the foregoing patent applications, patent publications, and patents is hereby incorporated by reference in its entirety.

BACKGROUND

The present disclosure relates to digital image capture and processing systems employing improved methods of automatic illumination control during a continuous video image capture mode of operation.

Auto-exposure methods used in imaging devices typically involve the steps of (a) acquiring an image with a certain exposure time, (b) analyzing the acquired image and (c) determining if an exposure period needs to be set, and (d) repeating these steps until the image exposure quality meets a predetermined threshold. In the case of imaging barcode scanners, sometimes the imager is running in video mode.

Therefore, if the previous exposure time is incorrect, while the computer is still analyzing the first acquired image, subsequent frame in the video is wasted since it is taken with the same exposure time. The resulting effect is a time-consuming auto-exposure method and at least one frame of the video is wasted.

U.S. Pat. No. 7,841,533 discloses hand-supportable digital-imaging code symbol reading devices employing improvements in automatic illumination and exposure control, in digital imaging applications. However, despite providing improvements in automatic illumination and exposure control, such techniques could still benefit from innovative adaptive measures which work to make digital-imaging based code symbol reading systems more responsive in demanding imaging environments.

Thus, there is a great need in the art for an improved method of and apparatus for reading code symbols using object illumination and imaging techniques which avoid the shortcomings and drawbacks of prior art methods and apparatus.

SUMMARY

Accordingly, a primary object of the present disclosure is to provide a novel digital image capture and processing system and method, which avoid the shortcomings and drawbacks of prior art methods and apparatus.

Another object is to provide a digital image capture and processing system having a digital image formation and detection subsystem, supporting a continuous video image capture mode, having a variable stroboscopically-pulsed illumination (i.e. strobe illumination) duration, synchronized with each image exposure period, so as to help provide an improved level of responsiveness while ensuring high-quality image capture performance.

Another object is to provide such a digital image capture and processing system, wherein its LED-based illumination subsystem has an array of LEDs, from which stroboscopically-pulsed (i.e. strobe) illumination is delivered to the field of view (FOV), while synchronized with the exposure period of each image capture frame.

Another object is to provide such a digital image capture and processing system, wherein the digital image formation and detection subsystem employs an optical band-pass filter designed to pass optical bandwidth of LED-based strobe illumination, during illumination transmission and collection operations, while blocking out optical components of ambient light residing outside the optical bandwidth of LED strobe illumination, thereby reducing the dynamic range of the image as well as improve the accuracy of exposure estimation based on previous images.

Another object is to provide a digital image capture and processing system, wherein upon detecting an object in the field of view (i.e. manually or automatically), the system commences its video image acquisition cycle by the LED array generating stroboscopically-pulsed illumination (i.e. strobe illumination) having energy levels that are significantly different for the first two digital image frames, so that the first strobe illumination is twice as bright as the second strobe illumination, and the first digital image is twice as bright as the second digital image in the video image stream; then these digital images are processed in an effort to read one or more code symbols graphically represented therein; and if successful, then the system returns to its initial detect object state.

Another object is to provide a digital image capture and processing system, wherein, according to a first illustrative embodiment, in the event that neither the first nor the second digital image captured by the system can be successfully decoded to read a bar code symbol, then the two digital images with different brightness levels are analyzed (in real-time) to determine a preferred exposure time duration, for subsequent video frames, based upon (i.e. depending on) whether both first and second digital images are too dark, too bright, or one image is too bright while the other image too dark.

Another object is to provide a digital image capture and processing system, wherein, according to a second illustrative embodiment, in the event that neither the first nor the second digital image captured by the system can be successfully decoded to read a bar code symbol, then the two digital images with different brightness levels are analyzed (in real-time) to determine a new strobe illumination energy level to enable the reading of code symbols graphically represented therein, without resetting the exposure time during subsequent image capture frames, based upon (i.e. depending on) whether the first and second digital images are too dark, or too bright, or whether one digital image is too bright and the other digital image is too dark.

These and other objects will become apparent hereinafter and in the Claims appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of how to practice the objects, the following detailed description of the illustrative embodiments can be read in conjunction with the accompanying drawings, briefly described below.

FIG. **1** is a perspective view of an illustrative embodiment of the hand-supportable digital image capture and processing system of the present disclosure, wherein its automatic object motion detection and analysis subsystem projects an IR-based illumination beam within the FOV of the system during its object detection mode, and where its LED-based illumination subsystem also employs an array of light emitting diodes (LEDs) to illuminate objects located anywhere within the working distance of the system;

FIG. **2**A is a first perspective exploded view of the hand-supportable digital image capture and processing system of the illustrative embodiment illustrated in FIG. **1**, and showing its PC board assembly arranged between the front and rear portions of the system housing, with the hinged base being pivotally connected to the rear portion of the system housing by way of an axle structure;

FIG. **2**B is a second perspective/exploded view of the hand-supportable digital image capture and processing system of the illustrative embodiment of the present invention shown in FIG. **1**;

FIG. **3** is a schematic block system diagram for the hand-supportable digital image capture and processing system illustrated in FIGS. **1** through **2**B;

FIG. **4** is a schematic representation of the operation of the image detection array employed in its video mode of operation, while an object in its field of view (FOV) is being illuminated with stroboscopic illumination, and digital video images are being captured, according to the principles of the adaptive strobe illumination and exposure control process of the present disclosure;

FIGS. **5**A through **5**D, taken together, provide a flow chart setting forth the steps involved in carrying out the adaptive strobe illumination control process of the first illustrative embodiment, involving (i) illuminating an object in the field of view (FOV) with several different strobe (i.e. stroboscopic) illumination pulses over a pair of consecutive image frames, (ii) detecting digital images of the illuminated object over these consecutive image frames, (iii) decode processing the digital images in an effort to read a code symbol graphically encoded therein, and upon failure to do so, (iv) analyzing these digital images, and based on the results of this real-time image analysis, automatically adjusting the exposure time (i.e. photonic integration time interval) during subsequent image frames (i.e. image acquisition cycles) according to the principles of the adaptive strobe illumination and exposure control process of the present disclosure; and

FIGS. **6**A through **6**D, taken together, provide a flow chart setting forth the steps involved in carrying out the adaptive strobe illumination control process of the second illustrative embodiment, involving (i) illuminating an object in the field of view (FOV) with several different strobe (i.e. stroboscopic) illumination pulses over a pair of consecutive image frames, (ii) detecting digital images of the illuminated object over these consecutive image frames, (iii) decode processing the digital images in effort to read a code symbol graphically encoded therein, and upon failure to do so, (iv) analyzing these digital images, and based on the results of this real-time image analysis, automatically adjusting the energy level of the strobe illumination during subsequent image frames (i.e. image acquisition cycles) according to the principles of the adaptive strobe illumination and exposure control process of the present disclosure.

DETAILED DESCRIPTION

Referring to the figures in the accompanying Drawings, the illustrative embodiments of the digital imaging-based bar code symbol reading system will be described in great detail, wherein like elements will be indicated using like reference numerals.

In general, two illustrative embodiments of the digital-imaging based bar code symbol reading system are described hereinbelow. In each illustrative embodiment, an adaptive strobe illumination and exposure control process is supported, which helps provide an improved level of snappiness and/or responsiveness to system performance.

As shown in FIGS. **1**, **2**A and **2**B, the digital-imaging based bar code symbol reading system of the illustrative embodiment 1 comprises: a hand-supportable housing **2** having (i) a front housing portion **2**B with a window aperture **6** and an imaging window panel **3** installed therein; and (ii) a rear housing portion **2**A. As shown, a single PC board based optical bench **8** (having optical subassemblies mounted thereon) is supported between the front and rear housing portions **2**A and **3**B which, when brought together, form an assembled unit. A base portion **4** is connected to the assembled unit by way of a pivot axle structure **131** that passes through the bottom portion of the imager housing and the base portion so that the hand-supportable housing and base portion are able to rotate relative to each other. The host/imager interface cable **10** passes through a port **132** formed in the rear of the rear housing portion, and interfaces with connectors mounted on the PC board **8**.

The hand-supportable digital-imaging based system **1** can be used in both hand-supportable and counter-top supportable modes of operation. When operated in its manually-triggered hand-supportable mode of operation, as shown in FIG. **4**A, the system supports first and second manually-triggered modes of bar code symbol reading operation, specified in FIGS. **5** and **6**, respectively. When operated in its automatically-triggered hand-supportable mode of operation, as shown in FIG. **4**B, the system supports first and second automatically-triggered modes of bar code symbol reading operation, specified in FIGS. **7** and **8**, respectively. When operated in its counter-top supportable mode of operation, the system supports an automatically-triggered mode of bar code symbol reading operation, allowing for full hands-free operation.

As shown in FIG. **3**, the digital-imaging based code symbol reading system **1** comprises a number of subsystem components, namely: an image formation and detection (i.e. camera) subsystem **21** having image formation (camera) optics **34** for producing a field of view (FOV) upon an object to be imaged and a CMOS or like area-type image detection array **35** for detecting imaged light reflected off the object during illumination operations in an image capture mode in which at least a plurality of rows of pixels on the image detection array are enabled; a LED-based illumination subsystem **22** employing a single LED illumination array **32** for producing a field of narrow-band wide-area illumination **126** within the entire FOV **33** of the image formation and detection subsystem **21**, which is reflected from the illuminated object and transmitted through a narrow-band transmission-type optical filter **40** realized within the hand-supportable housing and detected by the image detection array **35**, while all other components of ambient light are substantially rejected; an object targeting illumination subsystem **31** as described hereinabove; an IR-based object motion detection and analysis subsystem **20** for producing an IR-based object detection field **32** within the FOV of the image formation and detection subsystem **21**; an automatic illumination and exposure control subsystem **24** for controlling the operation of the LED-based illumination subsystem **22** and exposure time period of the image detection array **35**; an image capturing and buffering subsystem **25**

for capturing and buffering 2-D images detected by the image formation and detection subsystem **21**; a digital image processing subsystem **26** for processing 2D digital images captured and buffered by the image capturing and buffering subsystem **25** and reading 1D and/or 2D bar code symbols represented therein; an input/output subsystem **27** for outputting processed image data and the like to an external host system or other information receiving or responding device; and a system control subsystem **30** integrated with the subsystems above, for controlling and/or coordinating these subsystems during system operation.

The primary function of the object targeting subsystem **31** is to automatically generate and project a visible linear-targeting illumination beam **70** across the central extent of the FOV of the system in response to either (i) the automatic detection of an object during hand-held imaging modes of system operation, or (ii) manual detection of an object by an operator when s/he manually actuates the manually-actuatable trigger switch **5**. In order to implement the object targeting subsystem **31**, the OCS assembly **78** also comprises a fourth support structure for supporting the pair of beam folding mirrors above a pair of aperture slots. In turn, these aperture slots are disposed above a pair of visible LEDs arranged on opposite sides of the FOV optics **34** so as to generate a linear visible targeting beam **70** that is projected off the second FOV folding **75** and out the imaging window **3**, as shown and described in detail in US Patent Publication No. US20080314985 A1, incorporated herein by reference in its entirety.

The primary function of the object motion detection and analysis subsystem **20** is to automatically produce an object detection field **32** within the FOV **33** of the image formation and detection subsystem **21**, to detect the presence of an object within predetermined regions of the object detection field **32**, as well as motion and velocity information about the object there within, and to generate control signals which are supplied to the system control subsystem **30** for indicating when and where an object is detected within the object detection field of the system. As shown in FIG. **2**B, IR LED **90**A and IR photodiode **90**B are supported in the central lower portion of the optically-opaque structure **133**, below the linear array of LEDs **23**. The IR LED **90**A and IR photodiode **90**B are used to implement the automatic IR-based object motion detection and analysis subsystem **20**.

The image formation and detection (i.e. camera) subsystem **21** includes: image formation (camera) optics **34** for providing a field of view (FOV) **33** upon an object to be imaged; and a CMOS area-type image detection array **35** for detecting imaged light reflected off the object during illumination and image acquisition/capture operations.

The primary function of the LED-based illumination subsystem **22** is to produce a wide-area illumination field **36** from the LED array **23** when an object is automatically detected within the FOV. Notably, the field of illumination has a narrow optical-bandwidth and is spatially confined within the FOV of the image formation and detection subsystem **21** during modes of illumination and imaging, respectively. This arrangement is designed to ensure that only narrow-band illumination transmitted from the illumination subsystem **22**, and reflected from the illuminated object, is ultimately transmitted through a narrow-band transmission-type optical filter subsystem **40** within the system and reaches the CMOS area-type image detection array **35** for detection and processing. All other components of ambient light collected by the light collection optics are substantially rejected at the image detection array **35**, thereby providing improved SNR, thus improving the performance of the system.

The narrow-band transmission-type optical filter subsystem **40** is realized by (1) a high-pass (i.e. red-wavelength reflecting) filter element embodied within the imaging window **3**, and (2) a low-pass filter element mounted either before the CMOS area-type image detection array **35** or anywhere beyond the high-pass filter element, including being realized as a dichroic mirror film supported on at least one of the FOV folding mirrors **74** and **75**, shown in FIGS. **2**A and **2**B.

As shown in FIG. **2**B, the linear array of LEDs **23** is aligned with an illumination-focusing lens structure **130** embodied or integrated within the upper edge of the imaging window **3**. Also, the light transmission aperture **60** formed in the PC board **8** is spatially aligned within the imaging window **3** formed in the front housing portion **2**A. The function of illumination-focusing lens structure **130** is to focus illumination from the single linear array of LEDs **23**, and to uniformly illuminate objects located anywhere within the working distance of the FOV of the system.

As shown in FIG. **2**B, an optically-opaque light ray containing structure **133** is mounted to the front surface of the PC board **8**, about the linear array of LEDs **23**. The function of the optically-opaque light ray containing structure **133** is to prevent transmission of light rays from the LEDs to any surface other than the rear input surface of the illumination-focusing lens panel **3**, which uniformly illuminates the entire FOV of the system over its working range. When the front and rear housing panels **2**B and **2**A are joined together, with the PC board **8** disposed there between, the illumination-focusing lens panel **3** sits within slanted cut-aways formed in the top surface of the side panels, and illumination rays produced from the linear array of LEDs **23** are either directed through the rear surface of the illumination-focusing lens panel **3** or absorbed by the black colored interior surface of the structure **133**.

As shown in FIGS. **2**A and **2**B, the optical component support (OCS) assembly **78** comprises: a first inclined panel for supporting the FOV folding mirror **74** above the FOV forming optics, and a second inclined panel for supporting the second FOV folding mirror **75** above the light transmission aperture **60**. With this arrangement, the FOV employed in the image formation and detection subsystem **21**, and originating from optics supported on the rear side of the PC board, is folded twice, in space, and then projected through the light transmission aperture and out of the imaging window of the system.

The automatic illumination and exposure control subsystem **24** performs two primary functions, namely: (i) controls the operation of the LED-based illumination subsystem **22** so that that LED illumination array **23** generates stroboscopically-controlled (i.e. stroboscopic) pulses of illumination at a predetermined average energy level in synchronism with the exposure duration (i.e. photo-integration time period) set for the image detection array **35**, and (ii) controls the exposure duration (i.e. photo-integration time period) set for the image detection array **35**, as instructed by the system control subsystem **30** so that objects within the FOV of the system are optimally exposed to LED-based illumination and optimal high quality images are formed and detected at the image detection array **35**, with a high level of system responsiveness. FIGS. **5** and **6**, describe the precise manner in which the automatic illumination and exposure control subsystem **24** operates under the control of subsystem **30** in accordance with the first and second illustrative embodiments of the adaptive strobe illumination and exposure control process of the present disclosure.

The OCS assembly **78** also comprises a third support panel for supporting the parabolic light collection mirror segment

79 employed in the automatic exposure measurement and illumination control subsystem **24**. Using this mirror **78**, a narrow light collecting FOV is projected out into a central portion of the wide-area FOV **33** of the image formation and detection subsystem **21** and focuses collected light onto photo-detector **81**, which is operated independently from the area-type image sensing array, schematically depicted in FIG. **3** by reference numeral **35**.

The primary function of the image capturing and buffering subsystem **25** is (1) to detect the entire 2D image focused onto the 2D image detection array **35** by the image formation optics **34** of the system, (2) to generate a frame of digital pixel data for either a selected region of interest of the captured image frame, or for the entire detected image, and then (3) buffer each frame of image data as it is captured. Notably, in the illustrative embodiment, the system has both single-shot and video modes of imaging. In the single shot mode, a single 2D image frame (**31**) is captured during each image capture and processing cycle, or during a particular stage of a processing cycle as described in U.S. Pat. No. 7,841,533, incorporated herein by reference. In the video mode of imaging, the system continuously captures frames of digital images of objects in the FOV, as described in greater detail in FIGS. **5**A through **5**D and **6**A through **6**D.

The primary function of the digital image processing subsystem **26** is to process digital images that have been captured and buffered by the image capturing and buffering subsystem **25**, during modes of illumination and operation. Such image processing operations include image-based bar code decoding methods as described in U.S. Pat. No. 7,128,266, incorporated herein by reference.

The primary function of the input/output subsystem **27** is to support universal, standard, and/or proprietary data communication interfaces with external host systems and devices, and output processed image data and the like to such external host systems or devices by way of such interfaces. Examples of such interfaces, and technology for implementing the same, are given in U.S. Pat. Nos. 6,619,549 and 6,619,549, incorporated herein by reference in their entirety.

The primary function of the system control subsystem **30** is to provide some predetermined degree of control, coordination, and/or management signaling services to each subsystem component integrated within the system, as shown. While this subsystem can be implemented by a programmed microprocessor, in the preferred embodiments this subsystem is implemented by the three-tier software architecture supported on a micro-computing platform, as described in U.S. Pat. No. 7,128,266 and elsewhere hereinafter.

The primary function of the manually-actuatable trigger switch **5** integrated with the housing is to enable the user, during a manually-triggered mode of operation, to generate a control activation signal (i.e. trigger event signal) upon manually depressing the same (i.e. causing a trigger event), and to provide this control activation signal to the system control subsystem **30** for use in carrying out its complex system and subsystem control operations, described in detail herein.

The primary function of the system configuration parameter table **29** in system memory is to store (in non-volatile/persistent memory) a set of system configuration and control parameters (i.e. SCPs) for each of the available features and functionalities, and programmable modes of supported system operation, and which can be automatically read and used by the system control subsystem **30** as required during its complex operations. Notably, such SCPs can be dynamically managed as taught in great detail in copending US Publication No. US20080314985 A1, incorporated herein by reference.

FIG. **4** is illustrates the operation of the image detection array **23** when operated in its video mode of operation, while an object in its field of view (FOV) is being illuminated with stroboscopically-controlled pulses of illumination, and digital video images are being captured, according to the principles of the adaptive illumination and exposure control process of the present disclosure, to be described in greater technical detail herein below.

FIGS. **5**A through **5**D describe the steps involved when carrying out the adaptive strobe illumination and exposure control process of the first illustrative embodiment. In general, the process involves: (i) illuminating an object in the field of view (FOV) with several different pulses of strobe (i.e. stroboscopic) illumination over a pair of consecutive image frames; (ii) detecting digital images of the illuminated object over these consecutive image frames; (iii) decode processing the digital images in effort to read a code symbol graphically encoded therein; and upon failure to do so, (iv) analyzing these digital images in real-time, and based on the results of this real-time image analysis, automatically adjusting the exposure time (i.e. photonic integration time interval) during subsequent image frames (i.e. image acquisition cycles) according to the principles of the present disclosure. This adaptive process will now be described in greater detail below.

As indicated at Block A of the flow chart of FIG. **5**A, the first step involves initializing the System and its parameters and settings.

As indicated at Block B, upon detecting an object in the field of view (FOV) of the image formation and detection subsystem, the LED-based illumination subsystem illuminates the object in the FOV at a first strobe illumination energy level, while the image detection array detects a first digital image of the illuminated object using a predetermined exposure duration (i.e. photo-integration time period), and then the image capture and buffering subsystem captures and buffers the first digital image.

As indicated at Block C, the digital image processing subsystem attempts to read one or more code symbols graphically represented in the first digital image, and if successful, then generates symbol character data, which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system controller advances to Block D.

As indicated at Block D in FIG. **5**B, upon detecting an object in the FOV of the image formation and detection subsystem, the LED-based illumination subsystem illuminates the object in the FOV at a second strobe illumination energy level (twice the second strobe illumination energy level), while the image detection array detects a second digital image of the illuminated object using the same predetermined exposure duration (i.e. photo-integration time period), and then the image capture and buffering subsystem captures and buffers the second digital image.

As indicated at Block E, the digital image processing subsystem attempts to read one or more code symbols graphically represented in the second digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block A. If decode processing is not successful, then the system controller advances to Block F.

As indicated at Block F, the digital image processing subsystem analyzes both first and second digital images, and determines a modified exposure time duration, for subsequent video frames, based upon (i.e. depending on) whether both first and second digital images as analyzed measures too dark,

too bright, or one digital image measures too bright while the other digital image measures too dark.

As indicated at Block G in FIG. **5**G, the LED-based illumination subsystem illuminates the object in the FOV at the first strobe illumination energy level, while the image detection array detects a subsequent digital image of the illuminated object using the modified predetermined exposure duration (i.e. photo-integration time period), and then the image capture and buffering subsystem captures and buffers the subsequent digital image.

As indicated at Block H, the digital image processing subsystem attempts to read one or more code symbols graphically represented in the subsequent digital image, and if successful, then generates symbol character data, which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system controller advances to Block I.

As indicated at Block I in FIG. **5**I, the LED-based illumination subsystem illuminates the object in the FOV at the second strobe illumination energy level, while the image detection array detects a subsequent digital image of the illuminated object using the modified predetermined exposure duration (i.e. photo-integration time period), and then the image capture and buffering subsystem captures and buffers the subsequent digital image.

As indicated at Block J, the digital image processing subsystem attempts to read one or more code symbols graphically represented in the subsequent digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block A. If decode processing is not successful, then the system controller advances to Block A.

The adaptive strobe illumination and exposure control process specified above is carried by the system control subsystem **30** in an automated manner, so that the digital-imaging based code symbol reading system supports an improved level of image acquisition responsiveness.

FIGS. **6**A through **6**D describe the steps involved when carrying out the adaptive strobe illumination and exposure control process of the second illustrative embodiment. In general, the process involves: (i) illuminating an object in the field of view (FOV) with several different strobe (i.e. stroboscopic) illumination pulses over a pair of consecutive image frames; (ii) detecting digital images of the illuminated object over these consecutive image frames; (iii) decode processing the digital images in an effort to read a code symbol graphically encoded therein; and upon failure to do so, (iv) analyzing these digital images in real-time, and based on the results of this real-time image analysis, automatically adjusting the energy level of the strobe illumination during subsequent image frames (i.e. image acquisition cycles) according to the principles of the present disclosure. This adaptive process will now be described in greater detail below.

As indicated at Block A of the flow chart of FIG. **6**A, the first step involves initializing the System and its parameters and settings.

At Block B, upon detecting an object in the field of view (FOV) of the image formation and detection subsystem, the LED-based illumination subsystem illuminates the object in the FOV at a first strobe illumination energy level, while the image detection array detects a first digital image of the illuminated object using a predetermined exposure duration (i.e. photo-integration time period), and then image capture and buffering subsystem captures and buffers the first digital image.

At Block C, the digital image processing subsystem attempts to read one or more code symbols graphically represented in the first digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system controller advances to Block D.

At Block D in FIG. **6**B, upon detecting an object in the FOV of the image formation and detection subsystem, the LED-based illumination subsystem illuminates the object in the FOV at a second strobe illumination energy level (twice the second strobe illumination energy level), while the image detection array detects a second digital image of the illuminated object using the same predetermined exposure duration (i.e. photo-integration time period), and then the image capture and buffering subsystem captures and buffers the second digital image.

At Block E, the digital image processing subsystem attempts to read one or more code symbols graphically represented in the second digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system controller advances to Block F.

As indicated at Block F, the digital image processing subsystem analyzes both first and second digital images, and determines a modified exposure time duration, for subsequent video frames, based upon (i.e. depending on) whether both first and second digital images as analyzed measure too dark, too bright, or one digital image measures too bright while the other digital image measures too dark.

As indicated at Block G in FIG. **6**C, the LED-based illumination subsystem illuminates the object in the FOV at a first modified strobe illumination energy level, while the image detection array detects a subsequent digital image of the illuminated object using the same predetermined exposure duration (i.e. photo-integration time period), and then the image capture and buffering subsystem captures and buffers the subsequent digital image.

As indicated at Block H in FIG. **6**D, the digital image processing subsystem attempts to read one or more code symbols graphically represented in the subsequent digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system controller advances to Block I.

As indicated at Block I in FIG. **6**D, the LED-based illumination subsystem illuminates the object in the FOV at a second modified strobe illumination energy level, while the image detection array detects a subsequent digital image of the illuminated object using the same predetermined exposure duration (i.e. photo-integration time period), and then image capture and buffering subsystem captures and buffers the subsequent digital image.

As indicated at Block J in FIG. **6**D, the digital image processing subsystem attempts to read one or more code symbols graphically represented in the subsequent digital image, and if successful, then generates symbol character data which is sent to the host computer system, and the system controller returns to Block B. If decode processing is not successful, then the system controller advances to Block B.

The above-described adaptive strobe illumination and exposure control process is carried out by the system control subsystem **30** in an automated manner, so that the digital-imaging based code symbol reading system supports an improved level of image acquisition responsiveness.

While the illustrative embodiments of the present invention have been described in connection with various types of bar code symbol reading applications involving 1-D and 2-D

bar code structures, it is understood that the present invention can be used to read (i.e. recognize) any machine-readable indicia, dataform, or graphically-encoded form of intelligence, including, but not limited to bar code symbol structures, alphanumeric character recognition strings, handwriting, and diverse dataforms currently known in the art or to be developed in the future. Hereinafter, the term "code symbol" shall be deemed to include all such information carrying structures and other forms of graphically-encoded intelligence.

Also, digital imaging systems of the illustrative embodiments can also be used to capture and process (i.e. recognize) various kinds of graphical images including photos and marks printed on driver licenses, permits, credit cards, debit cards, or the like, in diverse user applications.

It is understood that the digital image capture and processing technology employed in bar code symbol reading systems of the illustrative embodiments may be modified in a variety of ways which will become readily apparent to those skilled in the art and having the benefit of the novel teachings disclosed herein. All such modifications and variations of the illustrative embodiments thereof shall be deemed to be within the scope of the Claims appended hereto.

The invention claimed is:

1. A method of controlling illumination processes within a digital image system having a field of view, comprising:
- illuminating an object in the field of view at a first energy level;
- capturing a first digital image of the object illuminated at the first energy level using a predetermined exposure duration;
- attempting to read a symbol in the first digital image;
- if a symbol is not read in the first digital image, illuminating the object in the field of view at a second energy level that is different from the first energy level;
- capturing a second digital image of the object illuminated at the second energy level using the predetermined exposure duration;
- attempting to read a symbol in the second digital image;
- if a symbol is not read in the second digital image, analyzing the first digital image and the second digital image to measure whether:
  - the first digital image and the second digital image are both too dark;
  - the first digital image and the second digital image are both too bright; or
  - one of the first digital image and second digital image is too bright and the other of the first digital image and second digital image is too dark;
- determining a modified energy level based on the analysis of the first digital image and second digital image;
- determining a modified exposure duration based on the analysis of the first digital image and second digital image;
- illuminating the object in the field of view at the modified energy level;
- capturing a first subsequent digital image of the object illuminated at the modified energy level using the modified exposure duration;
- attempting to read a symbol in the first subsequent digital image;
- if a symbol is not read in the first subsequent digital image, illuminating the object in the field of view at the second energy level;
- capturing a second subsequent digital image of the object illuminated at the second energy level using the modified exposure duration; and
- attempting to read a symbol in the second subsequent digital image.

2. The method of claim **1**, comprising filtering light reflected from the illuminated object to block ambient light, wherein the step of capturing a first digital image comprises capturing the first digital image from the filtered light.

3. The method of claim **1**, comprising filtering light reflected from the illuminated object to block ambient light, wherein the step of capturing a second digital image comprises capturing the first digital image from the filtered light.

4. The method of claim **1**, wherein the step of capturing a first digital image comprises capturing a first digital image using an area-type image detection array.

5. The method of claim **1**, wherein the step of capturing a first digital image comprises capturing a first digital image using a CMOS-type area-type image detection array.

6. The method of claim **1**, wherein the second energy level is greater than the first energy level.

7. A method of controlling illumination processes within a digital image system having a field of view, comprising:
- illuminating an object in the field of view at a first energy level;
- capturing, with a CMOS-type image detection array, a first digital image of the object illuminated at the first energy level using a predetermined exposure duration;
- attempting to read a symbol in the first digital image;
- if a symbol is not read in the first digital image, illuminating the object in the field of view at a second energy level that is different from the first energy level;
- capturing, with the CMOS-type image detection array, a second digital image of the object illuminated at the second energy level using the predetermined exposure duration;
- attempting to read a symbol in the second digital image;
- if a symbol is not read in the second digital image, analyzing the first digital image and the second digital image to measure whether:
  - the first digital image and the second digital image are both too dark;
  - the first digital image and the second digital image are both too bright; or
  - one of the first digital image and second digital image is too bright and the other of the first digital image and second digital image is too dark;
- determining a modified energy level based on the analysis of the first digital image and second digital image;
- determining a modified exposure duration based on the analysis of the first digital image and second digital image;
- illuminating the object in the field of view at the modified energy level;
- capturing, with the CMOS-type image detection array, a subsequent digital image of the object illuminated at the modified energy level using the modified exposure duration; and
- attempting to read a symbol in the subsequent digital image.

8. The method of claim **7**, comprising filtering light reflected from the illuminated object to block ambient light, wherein the step of capturing a first digital image comprises capturing the first digital image from the filtered light.

9. The method of claim **7**, comprising filtering light reflected from the illuminated object to block ambient light, wherein the step of capturing a second digital image comprises capturing the first digital image from the filtered light.

10. The method of claim **7**, wherein the second energy level is greater than the first energy level.

11. The method of claim 7, wherein the first energy level is twice the second energy level.

12. The method of claim 7, wherein the first energy level is greater than the second energy level.

13. A method of controlling illumination processes within a digital image system having a field of view, comprising:

illuminating an object in the field of view at a first energy level;

capturing a first digital image of the object illuminated at the first energy level using a predetermined exposure duration;

attempting to read a symbol in the first digital image;

if a symbol is not read in the first digital image, illuminating the object in the field of view at a second energy level that is different from the first energy level;

capturing a second digital image of the object illuminated at the second energy level using the predetermined exposure duration;

attempting to read a symbol in the second digital image;

if a symbol is not read in the second digital image, analyzing the first digital image and the second digital image to measure whether:

the first digital image and the second digital image are both too dark;

the first digital image and the second digital image are both too bright; or

one of the first digital image and second digital image is too bright and the other of the first digital image and second digital image is too dark;

determining a modified energy level based on the analysis of the first digital image and second digital image;

determining a modified exposure duration based on the analysis of the first digital image and second digital image;

illuminating the object in the field of view at the modified energy level;

capturing a subsequent digital image of the object illuminated at the modified energy level using the modified exposure duration; and

attempting to read a symbol in the subsequent digital image.

14. The method of claim 13, comprising filtering light reflected from the illuminated object to block ambient light, wherein the step of capturing a first digital image comprises capturing the first digital image from the filtered light.

15. The method of claim 13, comprising filtering light reflected from the illuminated object to block ambient light, wherein the step of capturing a second digital image comprises capturing the first digital image from the filtered light.

16. The method of claim 13, wherein the step of capturing a first digital image comprises capturing a first digital image using an area-type image detection array.

17. The method of claim 13, wherein the step of capturing a first digital image comprises capturing a first digital image using a CMOS-type area-type image detection array.

18. The method of claim 13, wherein the second energy level is greater than the first energy level.

19. The method of claim 13, wherein the first energy level is greater than the second energy level.

20. The method of claim 13, wherein the first energy level is twice the second energy level.

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